Embedded NERVE system for intelligent manufacturing of multifunctional composites for vehicles

Acellent Technologies Inc.

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Project ID: mat170

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Overview

Timeline

- Project start date – 7/1/2019
- Project end date – 3/31/2020
- Percent complete – 100%

Budget

Total project funding

- ✓ DOE share - $199,933
- ✓ Contractor share - $0
- ✓ Funding for FY2019 - $111,074
- ✓ Funding for FY 2020 - $88,859

Barriers and Technical Targets

- Reduction of manufacturing cost of composite structures to be comparable or less than metal
- Reduction in manufacturing variations of fiber reinforced composites via improved manufacturing methods, and modeling tools
- Efforts focus on overcoming key challenges to using these materials, including cost reduction, high-volume manufacturing and understanding, predicting, and improving durability.
- *2017 U.S DRIVE MTT Roadmap report, section 5.1

Partners

- Interactions /collaborations – University of Delaware
- Project lead – Acellent Technologies Inc.

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Relevance

Impact

Fiber reinforced composite materials are gaining importance in the automotive industries because of their high stiffness/strength, low weight potential and cost-effectiveness. However there are still limitations which restrict their wide-spread usage due to affordability and product quality issues. The current program will develop novel multi-functional sensors for use in optimizing the composite manufacturing process, improving manufacturing quality, increasing throughput by optimizing production rate, eliminating the need to scrap components due to poor quality and reducing overall costs by eliminating time-consuming post-fabrication inspections leading to high-volume production use in automotive industries.

Objectives

- Develop an innovative cradle-to-grave Networked Elements for Resin Visualization and Evaluation (NERVE) system consisting of embedded actuating and sensing elements to monitor and enhance all phases of the composite manufacturing process used in the automotive manufacturing industry.
  - ✓ Optimize the composite manufacturing process,
  - ✓ Monitor the resin flow during the filling and curing cycle
  - ✓ Improve manufacturing quality through real-time monitoring
  - ✓ Reduce overall costs by eliminating time-consuming post-fabrication inspections and enable new capabilities in the produced structural components by facilitating self-monitoring throughout the life of the part.

Milestones

Month	Milestones	Status
June/July 2019	▪ Kick-off, Project plan evaluated	▪ Complete
September 2019	▪ Sensor selection & prototype layer development	▪ Complete
October 2019	▪ Integration of sensors with preform and mold to ensure functional sensing and control during the resin injection and curing stages	▪ Complete
October 2019	▪ Development of Process Monitoring and Flaw Detection preliminary algorithms	▪ Complete
February 2020	▪ Prototype system testing and feasibility demonstration	▪ Complete
March 2020	▪ ROI for the NERVE system	▪ Complete

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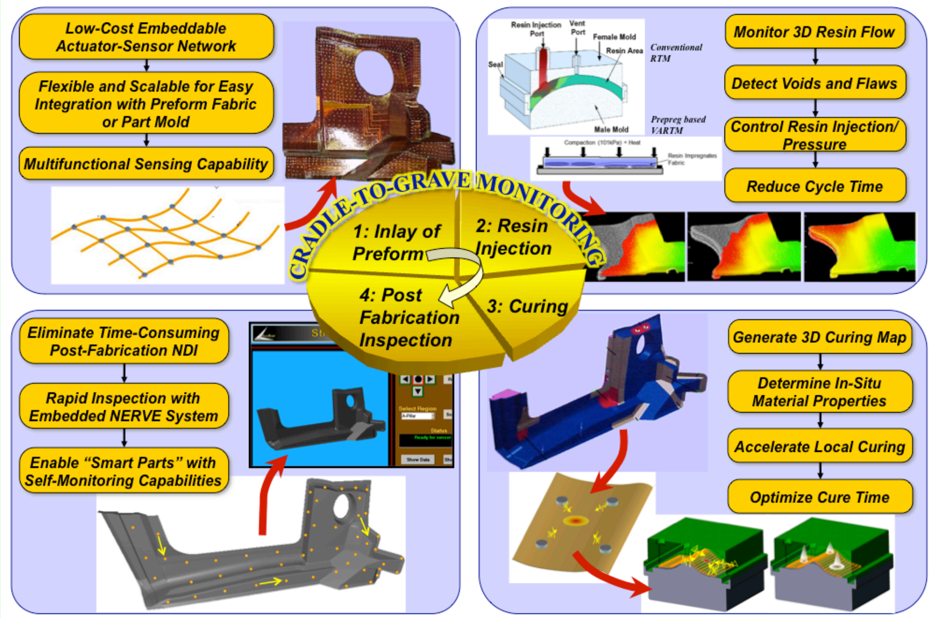
Approach

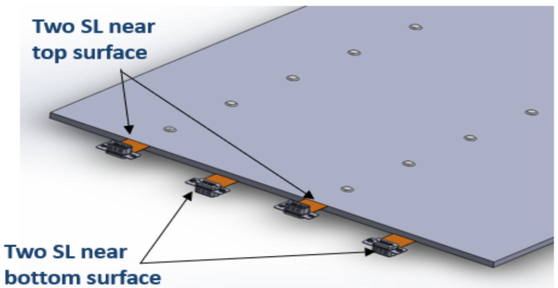
- The NERVE system utilizes an embedded sensor network for in-situ process monitoring and rapid comprehensive post-fabrication inspection.
- The system includes three major components – embedded sensor network, diagnostic hardware and process and damage monitoring software.
- Sensor network with piezoelectric transducers (actuators and sensors), temperature and heating elements will be strategically designed and embedded in the composite preform prior to manufacturing lay-up and/or below the surface ply of the composite mold.
- Portable diagnostic hardware is used to connect to the sensor network and obtain signals during the manufacturing process.
- The transducers in the sensor network will be used to send and receive diagnostic signals in the form of stress waves inside the composite to monitor the manufacturing process.
- The same sensor network once cured with the part will then be used for post-manufacturing damage monitoring during transportation and usage.



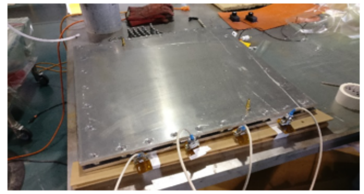
Embedded NERVE system for composite manufacturing processes

Technical Accomplishments & Progress

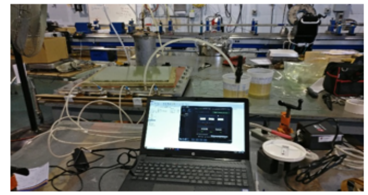
SMART Layer piezoelectric sensor network



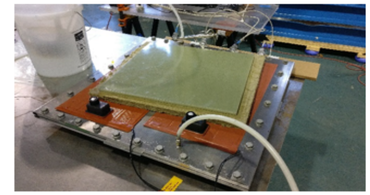
SMART Layer piezoelectric sensor network design for composite layup



Four SmartLayers placed between mold plates

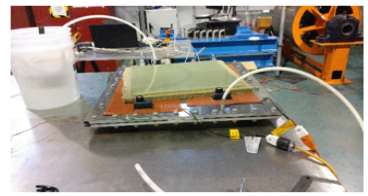


Acellent's SHM-Patch system for data collection

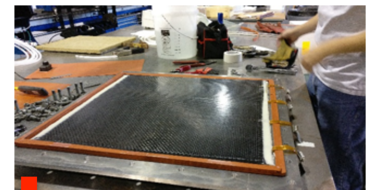


Resin flow pipe connected & cover with heating pad

Data collection during cure



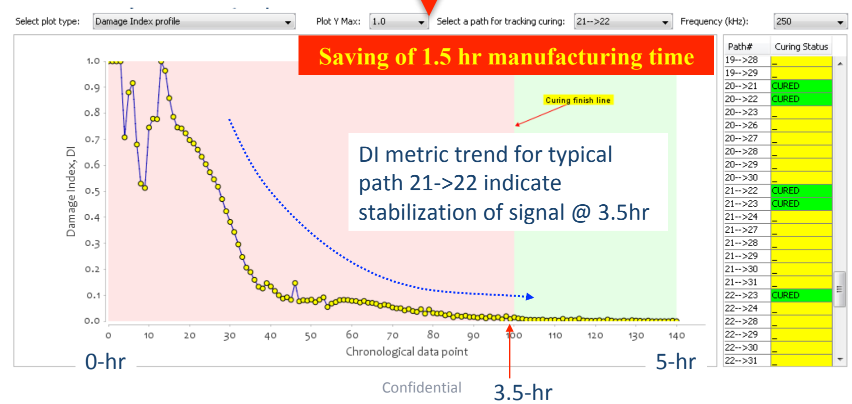
After ~5 hours test stopped,



Mold removed

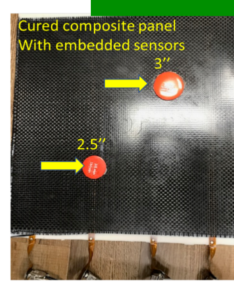
Composite manufacturing process

- Successfully embedded sensors during composite manufacturing process
- Curing algorithms developed provided information on cure state of structure
- Preliminary results indicated that the developed algorithms can detect when the part has cured and can save at least 30% manufacturing time for the composite part leading to manufacturing cost savings.
- The integrated sensors were also able to detect 100% damage simulated in the structure post manufacturing.

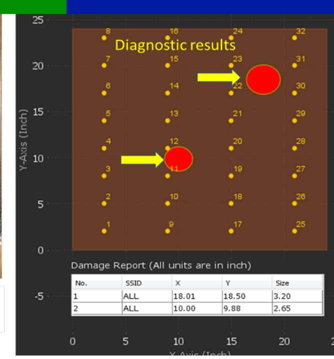


RESULTS

Cure monitoring



Case2: Two sticky patch mounted 2.5" and 3"



RESULTS

Damage detection with embedded sensors

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Technical Accomplishments and Progress Slide

- This is the first year that the project has been reviewed

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Collaboration and Coordination with Other Institutions

Collaborators *(Phase I and Phase II)*

- **University of Delaware** *(Phase I and Phase II)* - University of Delaware's Center for Composite Materials (CCM), 58,000 sq-ft, state-of-the-art, facilities and research equipment consist of the Manufacturing Sciences Laboratory (MSL) (34,000 sq-ft) and the Applications and Technology Transfer Laboratory, ATTL, an 24,000 Sq. ft. off-campus laboratory facility located approximately 3 miles from the MSL. Faculty, staff, and students have access to a broad spectrum of characterization, manufacturing, processing, and support equipment in the center and university.
- **BMW USA** *(Phase II and beyond)*
- **Armorworks** *(Phase II and beyond)* - ArmorWorks is a defense and security company providing innovative protective technologies and products worldwide. From commercial aviation cockpit doors to platform armor and seating to infrastructure and sensitive material protection, customers around the world depend on ArmorWorks technologies daily for security and protection of people and assets.

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Remaining challenges and barriers

The goal of the program is to reduce manufacturing cycle time and support the automotive industry in utilizing fiber-reinforced composites in high-volume production

Challenges

1. Building and integrating a sensor network into the composite material and/or mold. Embedded sensors in a composite structure or mold are regarded as foreign objects, and the compatibility of the sensors with the host structure is a major concern. The network must therefore be designed so that the sensor placement and wiring do not adversely affect the structural integrity of the part being manufactured.
2. Selection/evaluation of sensor types, optimum sensor locations, and algorithm development to accurately monitor and quantify a range of process parameters, including 3D resin flow front, location/size of voids, and local/global degree of cure. The physics of detection of each process parameter will have to utilize different sensor attributes, and thus will require separate algorithms.
3. Development of an innovative methodology for fast, effective and comprehensive assessment of the part quality to eliminate the current time-consuming post-fabrication inspections. The integrated sensors will be used to automatically detect any existing flaws and ascertain if the stiffness meets design requirements. When fully developed and implemented, these self-monitoring components can revolutionize the usage of composite structures, rendering them intelligent.

Proposed future research

Future tasks *(to be conducted in Phase II)*

1. Design of sensors for high-production composite manufacturing – Acellent will work with BMW and Armorworks composite manufacturing processes to develop the design of the sensors. Design will be developed for installation in 2 areas
   a. Sensors installed in mold
   b. Sensors installed in the part during manufacturing
2. Acellent will test the NERVE system using these 2 types of manufacturing processes, and associated sensor placement
3. Cure monitoring process detection for complex structures during manufacturing
4. Algorithm development for void and process detection
5. Damage detection on the manufactured composite parts
6. Fatigue testing with embedded sensors to ensure composite structural integrity
7. Comprehensive part assessment after manufacturing to generate a clear pathway for inclusion of the NERVE system into composite manufacturing process
8. Commercialization pathway with BMW and ArmorWorks

Any proposed future work is subject to change based on funding levels

Summary

Acellent Technologies Inc. in collaboration with subcontractor University of Delaware has successfully developed and demonstrated a prototype of an innovative cradle-to-grave Networked Elements for Resin Visualization and Evaluation (NERVE) system consisting of embedded actuating and sensing elements to monitor and enhance all phases of the composite manufacturing process used in the automotive manufacturing industry.

- Acellent worked with University of Delaware to develop the sensor design requirements for the composite manufacturing processes.
- Optimized placement of sensors and actuators was designed to ensure that the manufacturing defects during manufacturing and post-manufacturing damage during usage can be accurately detected.
- Sensor layers were designed to be placed on the top and bottom surfaces of the composite during the manufacturing process itself.
- Acellent's ScanGenie Mini hardware was utilized for data acquisition and functional verification in this application.
- The composite manufacturing process was carried out on composite test specimens at UDel and resin flow data collected.
- 3D rendering of resin flow was developed along with a preliminary algorithm to monitor degree of cure and to develop a preliminary algorithm for quality assurance and damage detection.
- Preliminary results indicated that the developed algorithms can detect when the part has cured and can save at least 30% manufacturing time for the composite part leading to manufacturing cost savings.
- The integrated sensors were also able to detect 100% damage simulated in the structure post manufacturing.

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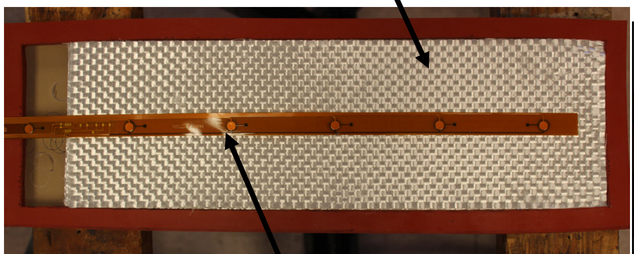
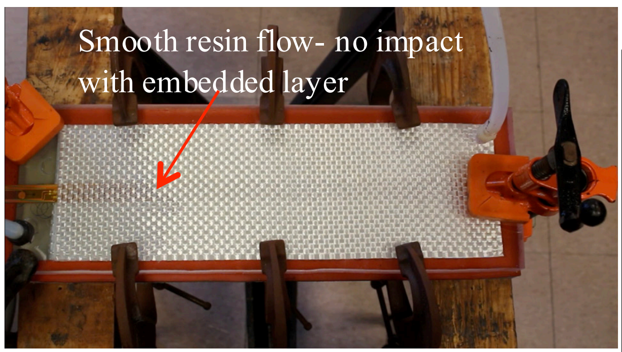
Technical backup slides

Resin flow check with embedded sensors

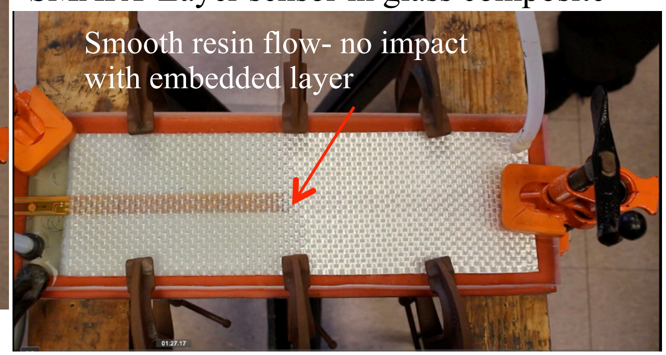
Glass composite

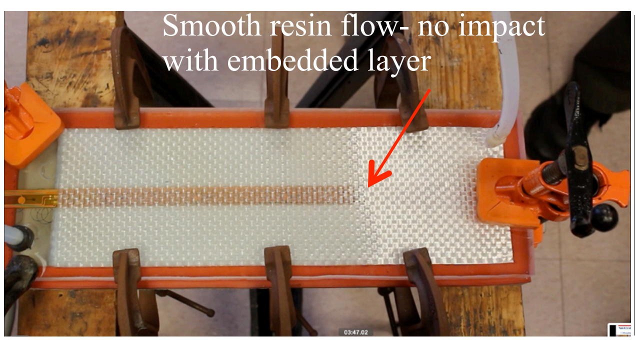


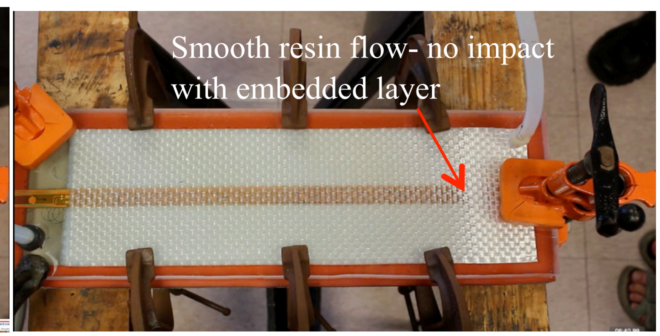
SMART Layer sensor



SMART Layer sensor in glass composite

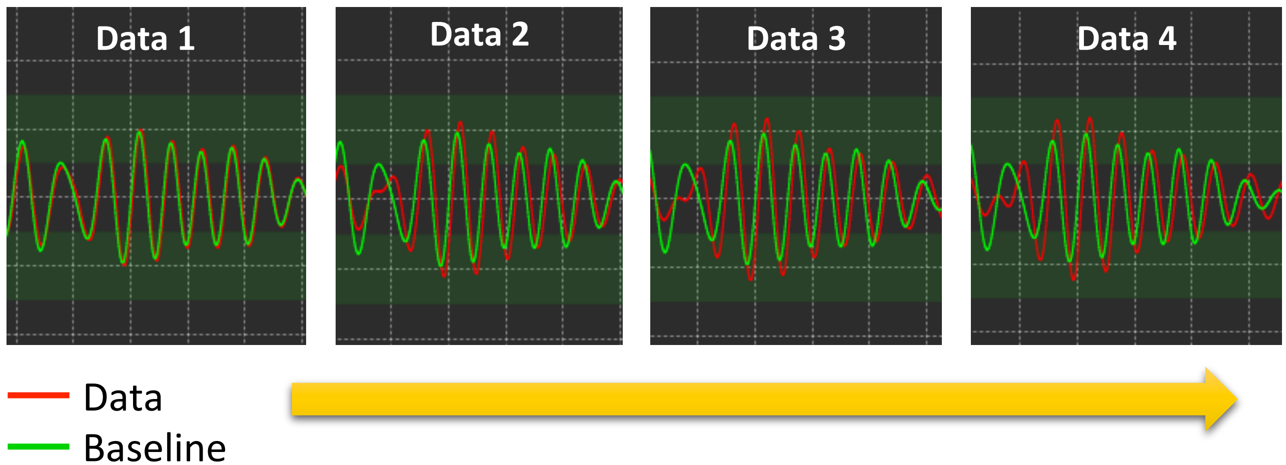




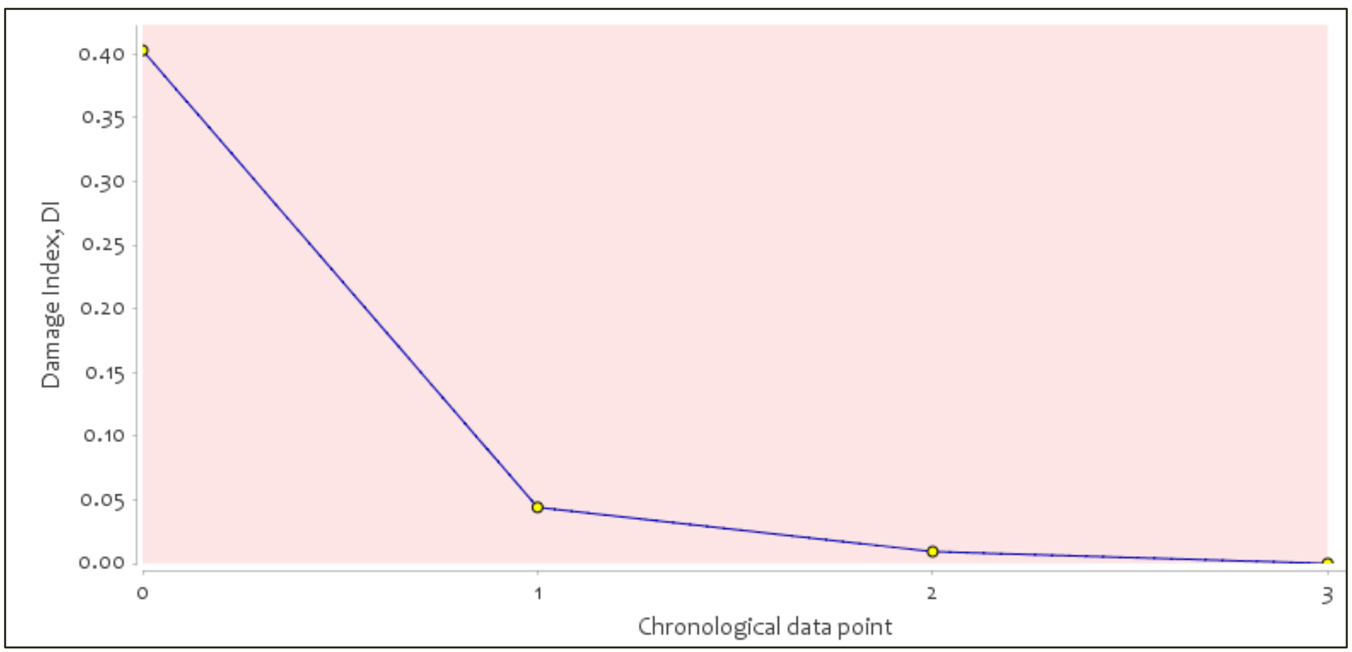


Technical backup slides

Resin Flow Modeling



Signal gets stronger with time. This indicates that the sensors are still curing.



Damage Index (DI)* converges slowly with each data.

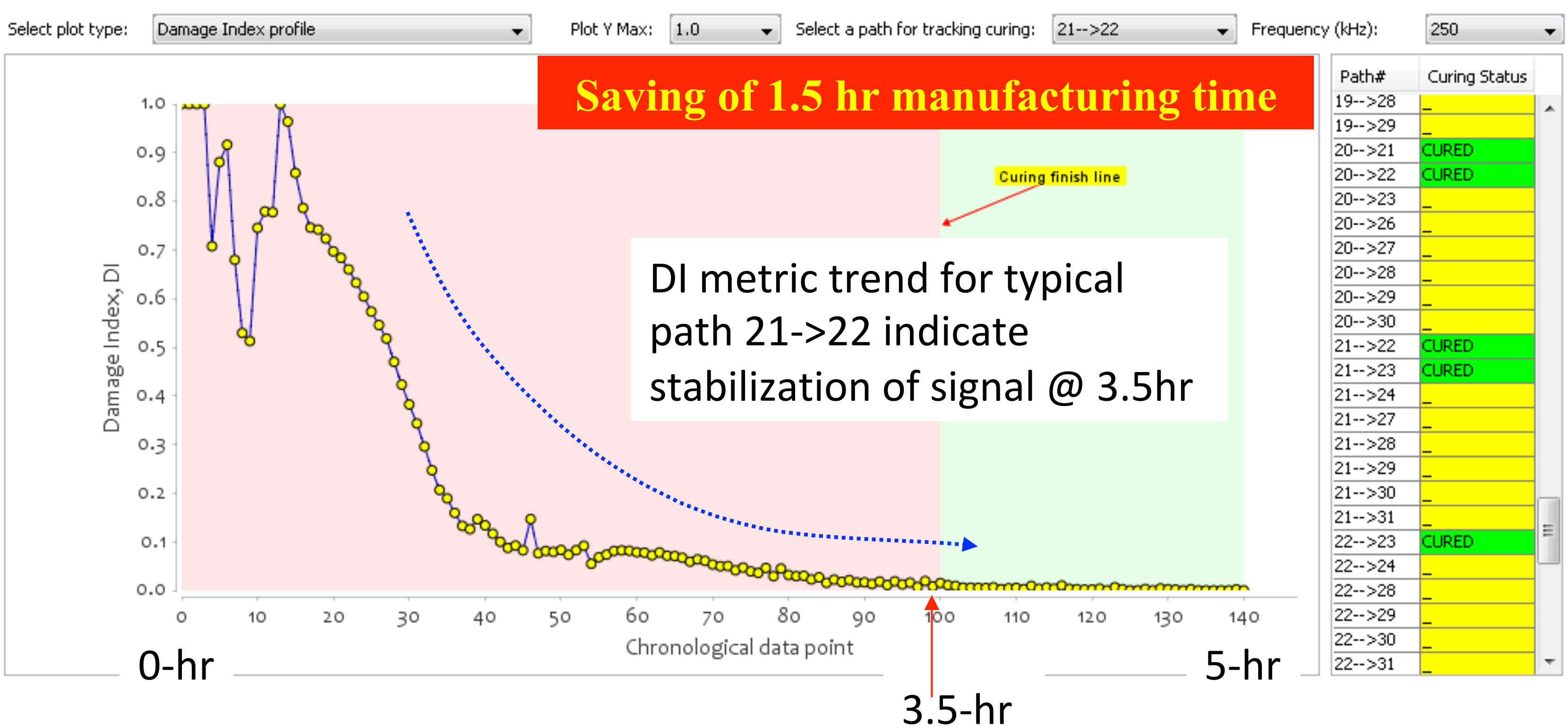
*Damage index is the metric that is used to measure the differential change in energy with respect to baseline signal.

Technical backup slides

Sensor waveform vs. curing progression

Time: 0 (start) **1hr** **>3.5hr**

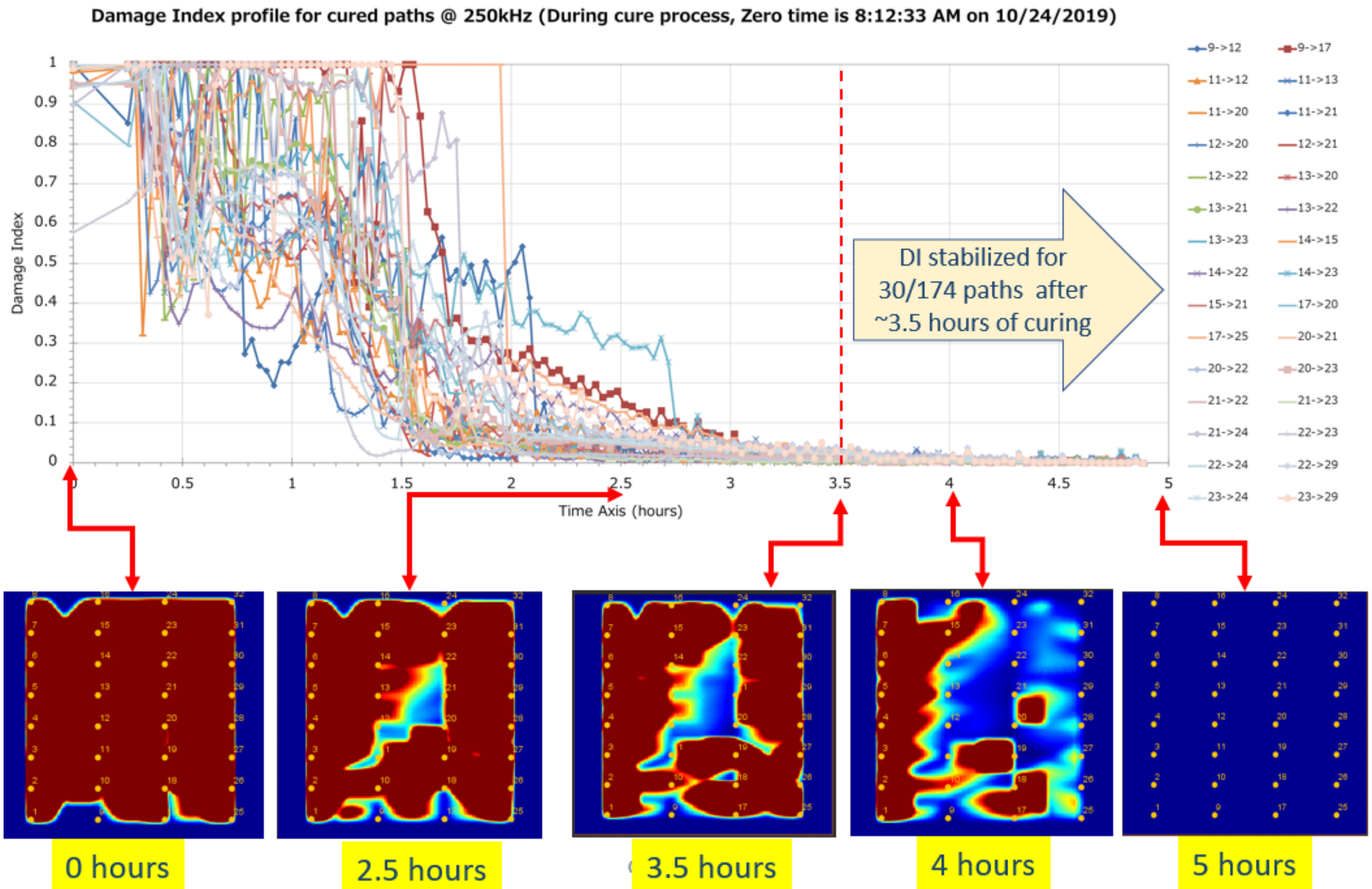
Waveform for path 21 → 22 growing stronger and stabilizes after ~3.5 hour of curing process



Technical backup slides

Damage Index Vs curing

Damage index* for almost all paths stabilizes after 3.5 hours, which can also be seen in the heat map. Dark red region indicates the region in the composite where the resin has still not cured while the dark blue region indicates the region in the CFRP panel which has already cured.

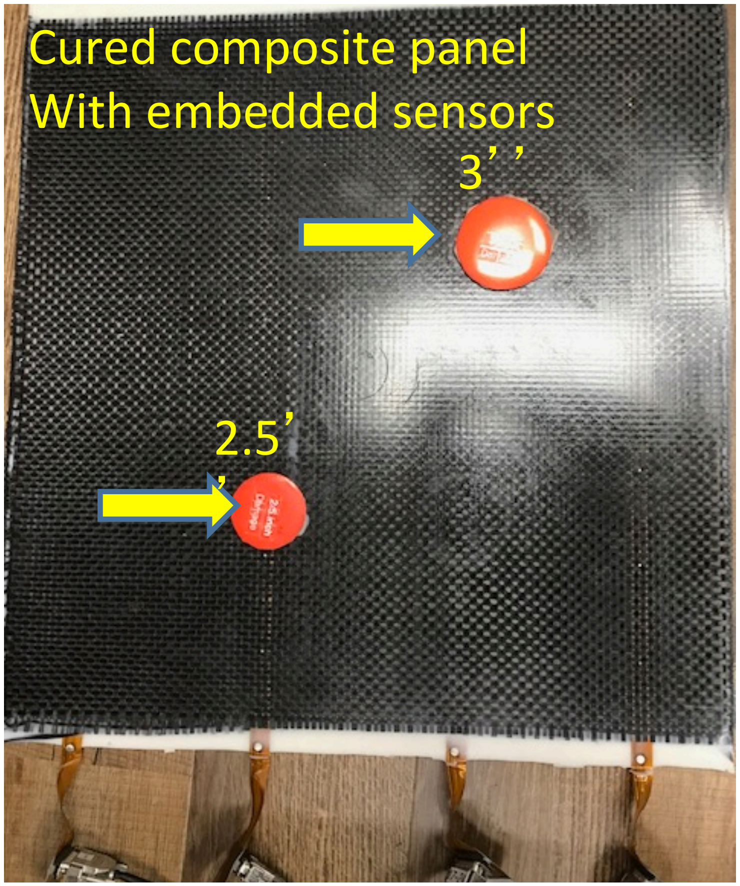


*Damage index is the metric that is used to measure the differential change in energy with respect to baseline signal.

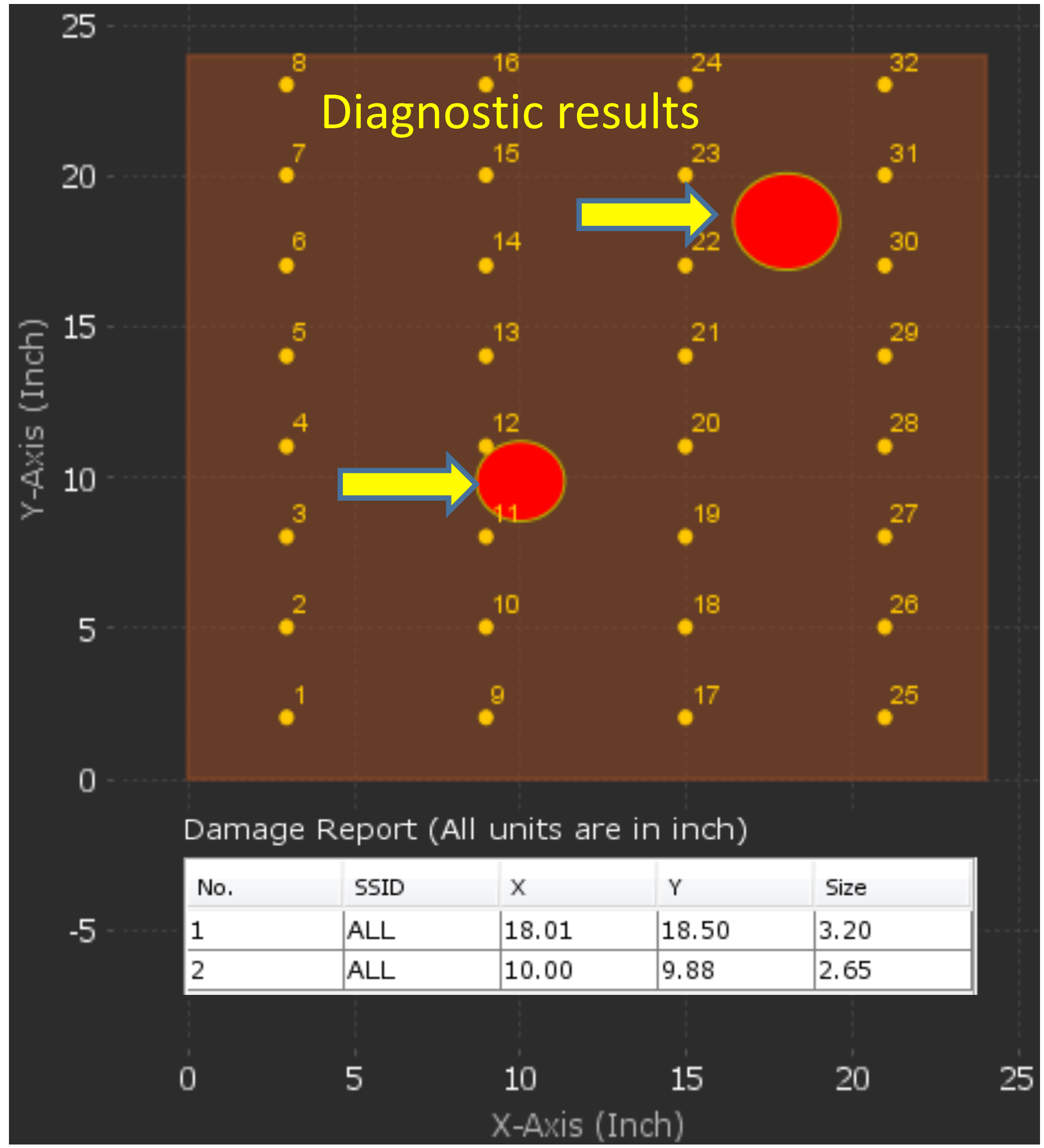
Technical backup slides

Damage Detection with damage simulators

Damage simulator sticky patch tested on cured composite panel



Two sticky patch(damage simulators) mounted on panel
Size - 2.5” and 3”



No.	SSID	X	Y	Size
1	ALL	18.01	18.50	3.20
2	ALL	10.00	9.88	2.65